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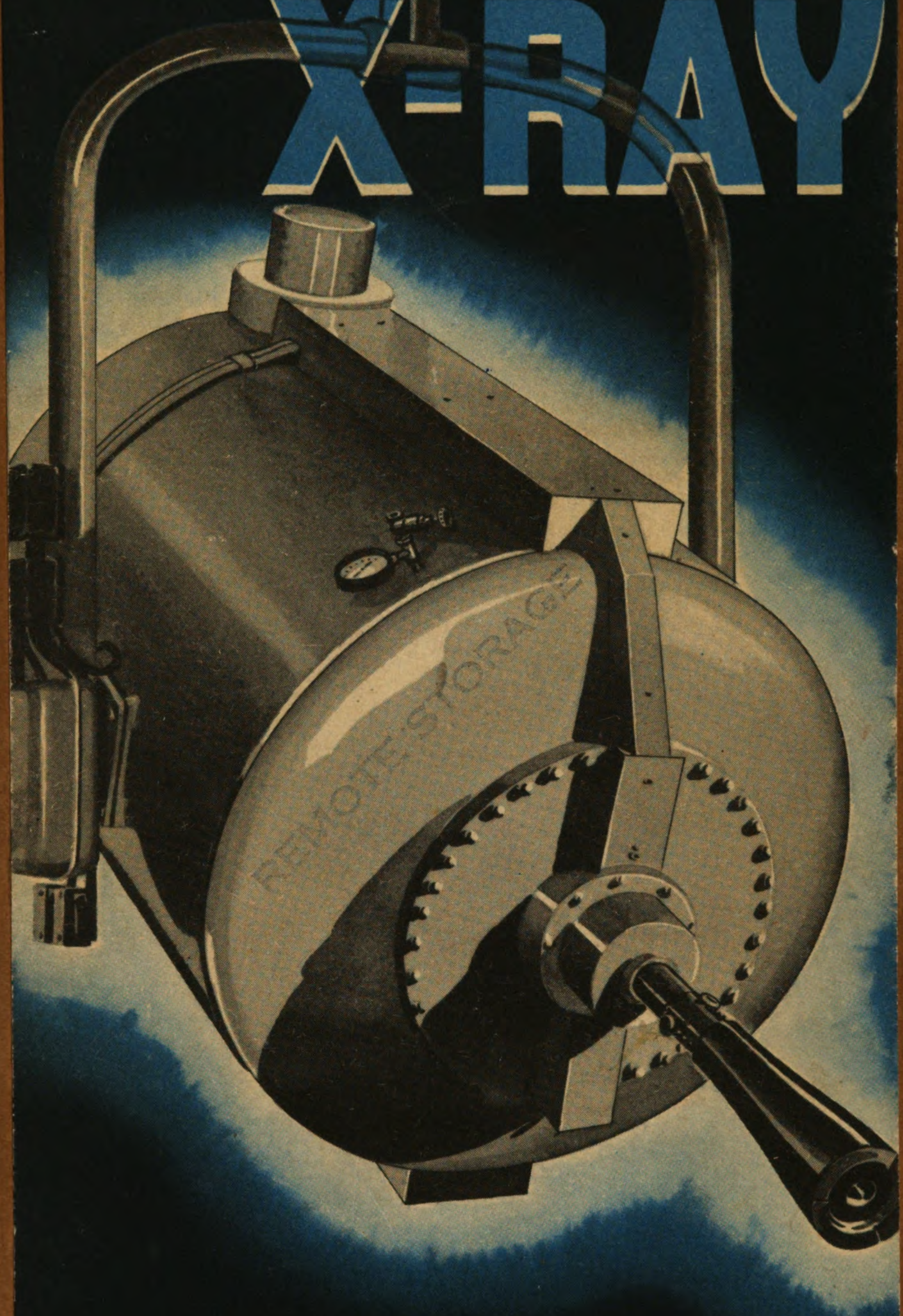
THE STORY OF X-RAY



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The Story of X-RAY

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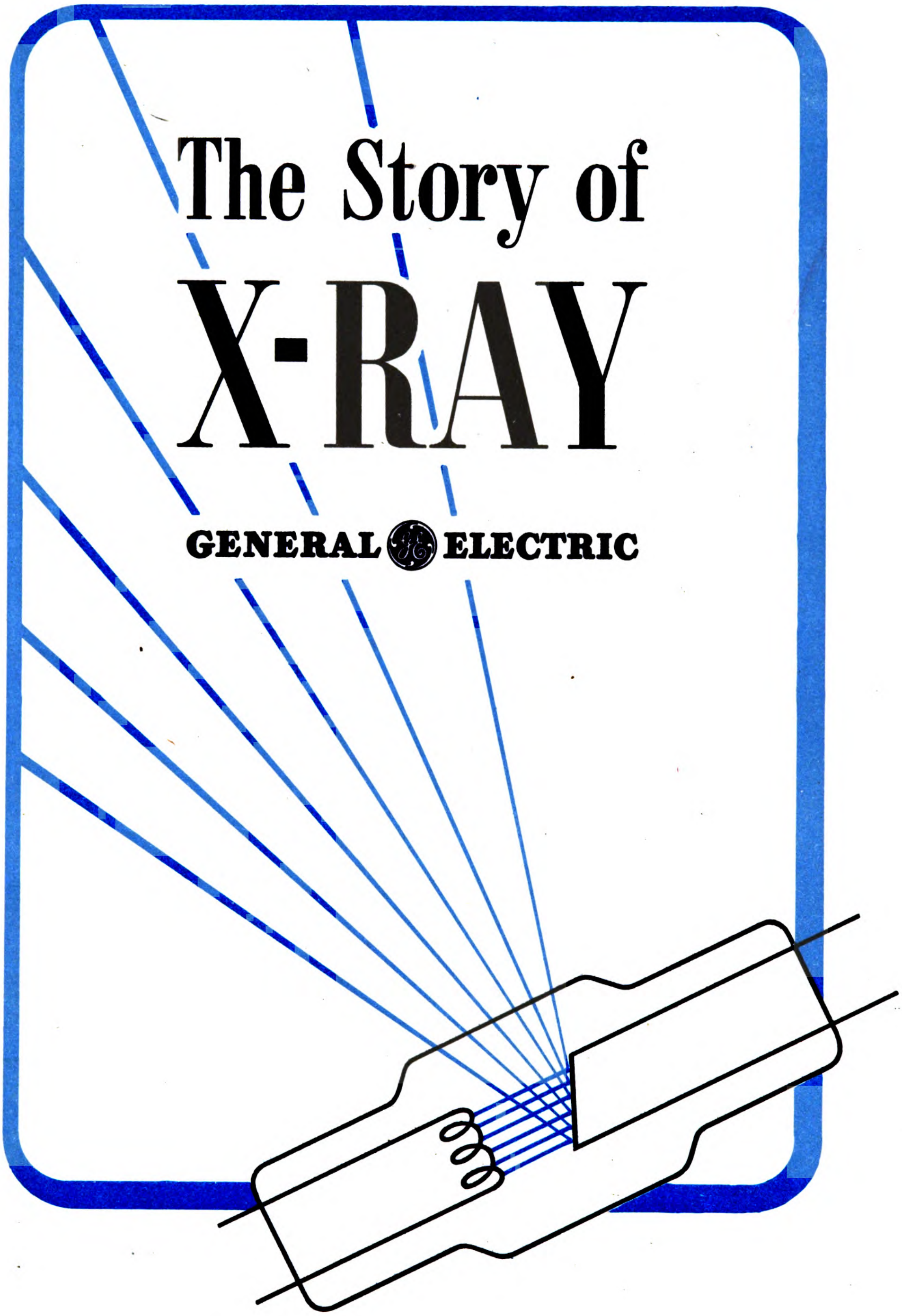

WILHELM KONRAD ROENTGEN
1845—1923

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ROENTGEN—GREAT DISCOVERER

IN NOVEMBER, 1895, an obscure physics professor, working in a modest little laboratory at the University of Wurzburg in Bavaria, came upon a mysterious ray which had the power to penetrate flesh, cloth, wood, and metal. This tall, slender, bearded teacher was Wilhelm Konrad Roentgen.

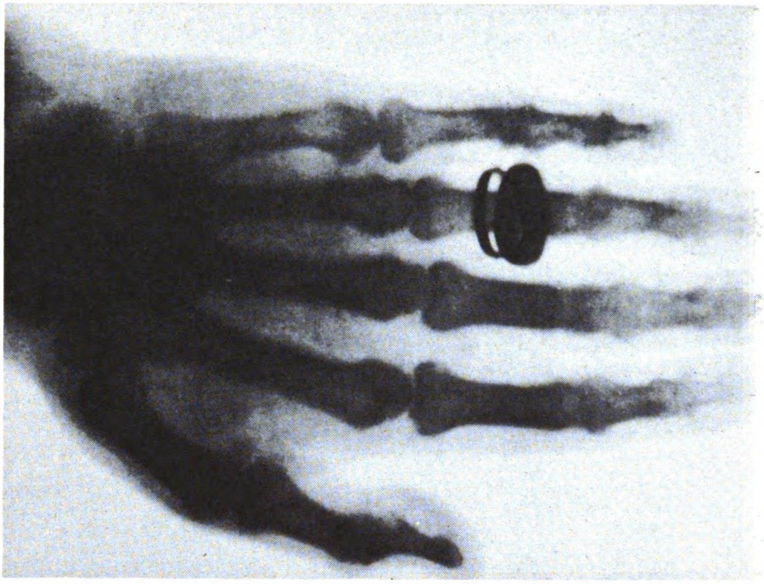
Using the mathematical symbol "X" for the unknown quantity, he called his discovery the x-ray.

When he first came upon the new "wonder ray," so powerful that it could pass through opaque objects, Roentgen told his good friend, Boveri: "I have discovered something interesting, but I do not know whether or not my observations are correct." Except for this remark, he talked to no one about what he had found. For days he locked himself in his laboratory and, without sleep or food, worked out his experiments again and again.

Certainly there was nothing elaborate about his laboratory to inspire him. There was a wide table shelf on one side of the room, in front of two high windows which gave plenty of light. In the center was a stove; on the left a small cabinet whose shelves held the small objects the professor was using. There was a table in the left-hand corner, and another small table—the one on which the bones of living human beings were first radiographed—was near the stove.

The apparatus used by Roentgen in making his discovery represented the labor of many students and scientists in centuries past. All had contributed something to developing knowledge of the characteristics of electricity and to the methods of its production, beginning with the creation of high-tension currents and continuing on to the study of various effects produced by such currents in a vacuum.

One of these scientists was Michael Faraday who, in 1837, carried out brilliant research on the luminous effects created in various gases by electric discharges. Percy Ghent, in his biography of Roentgen, said that to the patient study and



Roentgen made this radiograph January 23, 1896—hand of Professor von Kölliker of Wurzburg's Physical Institute

endless experiments of this modest Englishman, and his discovery of the phenomenon of electro-magnetic induction, we are indebted largely for the production of electric power as we now have it. His work marked the true beginning of the long series of investigations that ultimately brought about the discovery of the x-ray.

An important forward step toward Roentgen's discovery was made by Plücker, for whom Geissler had produced the first tube in which a vacuum, although a low one, could be indefinitely maintained. Electrodes of platinum wire were fused into the walls of the Geissler tube, which Plücker then excited with electric current, creating attractive luminous colors at the cathode end.

Later, Hittorf made important researches leading to the discovery of hitherto unsuspected rays which appeared to originate at the negative pole. Scant attention was paid to them, however, until the absorbing experiments of Crookes in 1879. Hertz, in 1892, conducted experiments which led him to the conclusion that the cathode stream could pass through the glass walls of the tube, and suggested further investigation outside the vacuum. After Hertz's death, his pupil, Lenard, carried on the experiments of his teacher, coaxing the cathode stream out of the tube through an aluminum window, and noted its effects, including the fogging of photographic emulsion. The work of Hertz and Lenard were the final steps of a long journey in science before the actual discovery of the x-ray.

Most scientists agree that Crookes, with his relatively high vacuum tube, produced x-rays; yet did not actually discover them. It remained for the 50-year-old Professor Roentgen to discover that the rays emanating from a Crookes tube, when a high-voltage current is sent through it, will penetrate objects opaque to ordinary light and will affect the photographic plate.

It is interesting to read the story of this momentous discovery as written by a man who interviewed Roentgen for an American magazine. This correspondent—for *McClure's* —reported . . .

"Now, professor, will you tell me the history of the discovery?"

"There is no history," Roentgen replied. "I have been for a long time interested in the problem of the cathode rays from a vacuum tube, as studied by Hertz and Lenard. I had followed theirs, and other researches with great interest, and determined, as soon as I had time, to make some researches of my own. I had been at work for some days when I discovered something new."

"What was the date?"

"The eighth of November."

"And what was the discovery?"

"I was working with a Crookes tube covered by a shield of black cardboard. A piece of barium platinocyanide paper lay on the bench there. I had been passing a current through the tube, and I noticed a peculiar black line across the paper."

"What of it?"

"The effect was one which could only be produced, in ordinary parlance, by the passing of light. No light could come from the tube, because the shield which covered it was impervious to any light known, even that of the electric arc."

"And what did you think?"

"I did not think; I investigated. I assumed that the effect must have come from the tube, since its character indicated that it could come from nowhere else. I tested it. In a few minutes there was no doubt about it. Rays were coming from the tube which had a luminous effect upon the paper. I tried it at greater and greater distances, even at two metres. It seemed at first a new kind of invisible light. It was clearly something new; something unrecorded."

"Is it light?"

"No."

"Is it electricity?"

"Not in any known form."

"What is it?"

"I don't know."

The first published report of Roentgen's discovery appeared in the December 28 issue of "The Transactions of the Physico-Medical Association." It was not till two months after his actual discovery—on January 23, 1896—that Roentgen officially reported his findings in a paper, "A New Kind of Ray," presented to the Physical Medical Society of Wurzburg. His report became news that electrified the world, spreading like wildfire.

Newspapers all over the world printed ghastly skeletons of hands and feet of living persons and extolled the mysterious power of those strange rays which could "see" through almost anything. The accounts, many of them displaying a curious ignorance and pessimism, were enough to arouse an assemblyman in New Jersey to introduce a bill in the House prohibiting the use of x-rays in opera glasses at theaters; and in London a firm "made prey of the ignorant women by advertising x-ray-proof clothing."

New York newspapers went so far as to say that the new rays might solve such age-old problems as spiritualism and soul photography. One paper reported that the Roentgen rays were used at the College of Physicians and Surgeons to reflect anatomic diagrams directly into the brain of students, thereby making a much more enduring impression than the ordinary methods of learning.

The stories and tales gradually grew to such feverish heights that the London *Pall Mall Gazette* came forth with the laconic statement: "We are sick of the Roentgen rays. Perhaps the best thing would be for all civilized nations to combine to burn all the Roentgen rays, to execute all the discoverers, and to corner all the equipment in the world and to whelm it in the middle of the ocean. Let the fish contemplate each other's bones if they like, but not us."

With almost equal prejudice, one of Roentgen's fellow-countrymen, in an article on German intellectualism, published a contemptible statement that the Wurzburg professor was a mercenary—"selling his discovery to the world for what it would fetch." Actually, the professor, by publicly describing his experiments and inviting the world to join in the x-ray's development, made it public property, beyond the reach of exploitation for the benefit of himself or other private interests.

In contrast to the skeptics were many strong believers in what Roentgen had found; especially medical men who could foresee how the sufferings of mankind might be lessened by the ministrations of these new rays. The acclaim of such scientists helped to make Roentgen famous overnight. Whether he liked it or not, Roentgen was showered with honors. He was summoned to the Royal Palace at Potsdam, where he dined with Wilhelm II, emperor of Germany and king of Prussia. A government decree bestowed upon him the title of "Excellency," boulevards and streets were named for him, and monuments were erected in his honor.

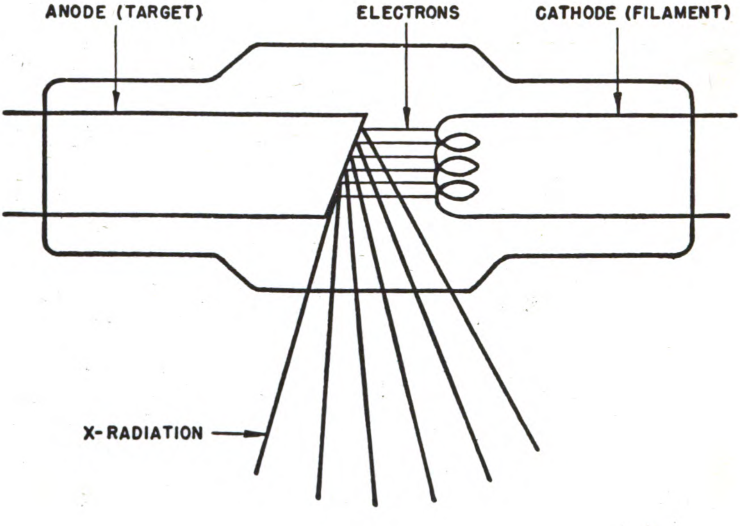
Roentgen died in 1923 at the age of 78. He virtually made a gift of his x-ray to humanity, seeking no reward and receiving no monetary gain from the great discovery, except the Nobel prize for physics awarded him in 1901.

HOW X-RAYS ARE PRODUCED

X-RAYS are similar in many respects to visible light. Both belong to that class of wave-like electromagnetic radiations that stretches from the electric and radio waves to the gamma rays of radium and on beyond the cosmic rays. The basic difference is in the wavelength, x-ray waves being much shorter than the waves of visible light.

To understand how x-rays are produced, it is first necessary to consider the electron—that negatively charged particle that is one of the smallest of the fundamental building blocks of matter. It has been calculated that 30,000 trillion trillion (that's 30 with 27 zeros after it) electrons weigh less than an ounce. Yet the electron can be a powerful thing. For when an electron is accelerated by a high electric voltage, it becomes a projectile which travels at an awesome speed. Under a voltage of 50,000 volts an electron will attain a velocity of 77,200 miles per second; if the voltage is 400,000 volts, the electron speed will approximate 155,000 miles per second, or 83 per cent the velocity of light. Notice that this is not a simple, direct relationship—for in the example just given an

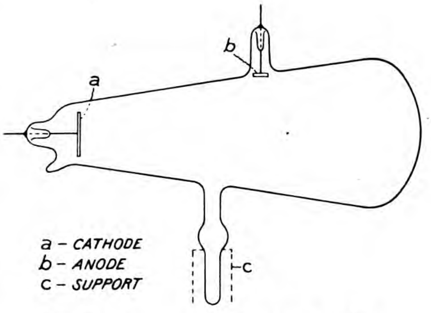
Electrons strike the anode and release x-radiation



eight-fold increase in voltage just about doubles the electron speed.

When millions and millions of these tiny speeding electrons strike a metal target, they penetrate the very atoms of the metal. And they produce, deep within the atomic structure, dislocations and rearrangements which, in turn, release the radiations we know as x-rays. The faster the electrons are traveling when they hit—that is, the higher the voltage on the x-ray tube—the more penetrating is the x-radiation.

Roentgen made his discovery while experimenting with a Crookes tube. It was a simple pear-shaped vacuum tube which had two metal electrodes—a cathode and an anode. The cathode, or negative electrode, was connected to one terminal of an induction coil; the anode, or positive electrode, was connected to the other. Electrons were shot out from the cathode at speeds of approximately 30,000 miles per second. They traveled so fast that most of them could not turn the corner to get to the anode, but instead hit the glass at the end of the tube. This impact of electrons upon the glass produced the x-rays which Roentgen observed.

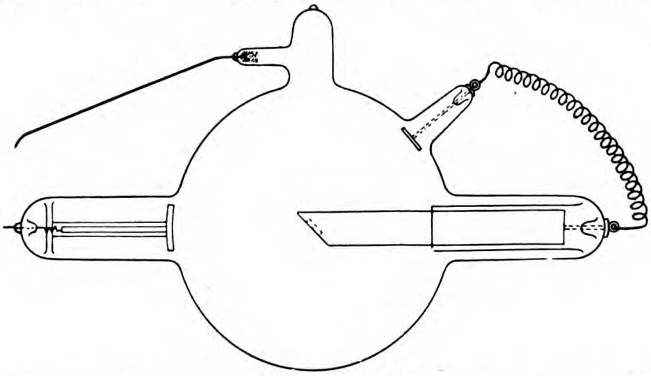


Earliest type of Roentgen tube

Fortunately, Roentgen did not have much power at his disposal, nor a sharp focal spot within the tube; otherwise the heat developed by the impact of the particles of electricity would have melted his glass tube. The focal spot, which is the area of bombardment by the electron stream, was extremely large in the old Crookes tube, being at least an inch square as compared with the present-day size of only a few square millimeters.

The earliest form of electrical generator to operate the x-ray tube was the induction coil, which in Roentgen's period was of primitive pattern. The discovery of these useful rays, however, gave great stimulus to the development of this piece of apparatus, and soon afterward induction coils were constructed having an electrical potential of many thousands of volts. Later, static machines, and then step-up transformers were developed to supply the high potential.

The early type of tube used to produce x-rays contained a considerable amount of residual gases and was known as a gas tube. This gas tube, even at its best, was an uncertain factor in much of the pioneer x-ray work. While it might be functioning perfectly one day, it would be found unfit for the same purpose the next day. This was largely due to the absorption of gases when the metal electrodes inside the tube became heated. The variations in gas pressure were too great to assure steady everyday performance. The addition or subtraction of even a minute percentage of gas greatly modified the tube's behavior.

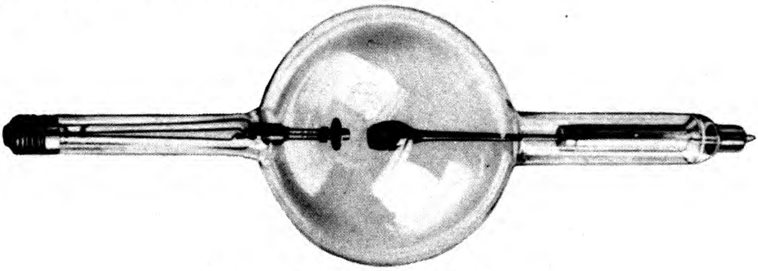


The gas tube was used in much of the pioneer x-ray work

As time went on many developments contributed to better designed gas tubes, and they were standardized to much the same general form. Among the developments introduced were the curved cathode by H. Jackson and the platinum target by Campbell Swinton, an Englishman. The curved cathode focused the electrons upon a smaller area, thus providing an approximate equivalent of a point source. Use of the platinum target not only protected the glass from bombardment but also, because of the high atomic weight and high melting point of the platinum, which permitted the use of higher electrical energies, made it possible to obtain a greater yield of x-rays.

It was only 18 years after Roentgen's discovery—in 1913—that William David Coolidge, who later became vice president and director of research for the General Electric Company, announced the development of a new x-ray tube which revolutionized the making of radiographs. His new tube made it possible for the operator to control the output of x-rays.

Dr. Coolidge found that tungsten had a much higher melting point, higher heat conductivity, and lower vapor pressure than platinum, and that with all these fine qualities it could be substituted for platinum, thereby producing a better and higher-powered x-ray tube.



An early type of Coolidge tube

Tungsten was a most brittle metal, more fragile than an eggshell. The first tungsten filaments in incandescent lamps were formed by squirting a paste of powdered tungsten through a die; then heating it to drive out the binder and to sinter the tungsten particles into a coherent, though fragile, filament. In order to give even better and stronger filaments, especially in larger sizes, Dr. Coolidge developed an improved process for squirting filaments. Still, he was not satisfied. In the face of the tradition that tungsten could not be deformed even slightly, he set out to prove that it could be rendered ductile.

Then, after more years of research, he produced what no man had seen before—a piece of tungsten which had lost its brittleness; which could be bent even when cold . . . ductile tungsten! His research proved that the longer tungsten is worked, the more ductile it becomes; whereas other metals under this process lose their ductility and turn brittle.

Dr. Coolidge's discovery, incidentally, has been of inestimable value in the manufacture of incandescent lamp filaments.

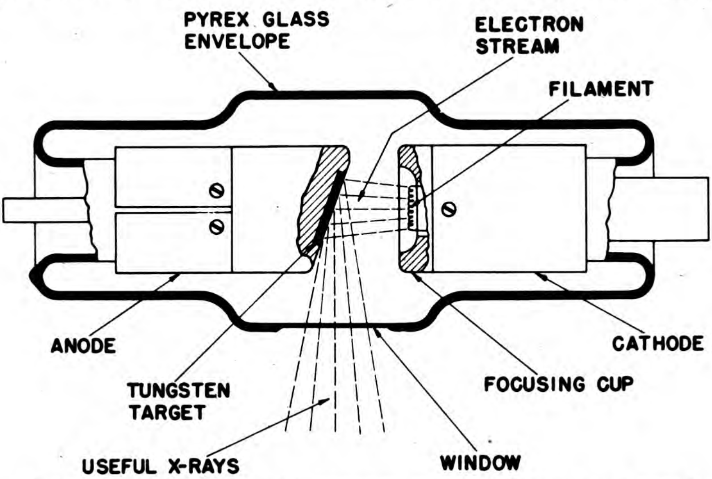
His research with tungsten gradually led to a point where he devised a technique for vacuum-casting copper around a tungsten disk or target. This technique improved heat conductivity of the x-ray tube's anode structure so that increased energy could be applied on the target to produce a greater quantity of x-rays of greater penetrating power. Tungsten is universally used today for targets, except in those tubes built for special purposes, such as diffraction.

The use of tungsten for targets, however, was not Dr. Coolidge's greatest contribution to the x-ray science. When Dr. Irving Langmuir, his associate in the G-E Research Laboratory, demonstrated the possibility of a pure electron discharge in high vacuum, Dr. Coolidge perceived the possibility of a radically new type of x-ray tube. His idea was to build a tube which would be both readily and accurately controllable, and wholly stable—something impossible with gas tubes.

He discovered that an x-ray tube could be made to operate with consistency if the cathode consisted of tungsten and was heated to incandescence and if the vacuum in the tube was made as nearly perfect as possible. With such a tube, it would no longer be necessary for the radiologist to have a rack of tubes handy, each one marked to indicate what particular set of circumstances was necessary to operate it properly.

Many were the problems which Dr. Coolidge had to solve before he finally attained his goal. But triumph he did, and the Coolidge x-ray tube soon substantially superseded all previous types. The first model of the Coolidge tube was capable of sustained, stable operation at voltages as high as 140,000, and later a model was designed for 200,000 volts.

The modern Coolidge tube, like earlier tubes, contains two metal electrodes, the cathode and the anode. But the cathode structure contains a spiral filament of tungsten wire which is heated by an electric current to such an incandescent temperature that electrons are boiled off it continuously. The anode is made of a solid block of tungsten imbedded in a massive copper structure. When a voltage is applied across the cathode and the anode, the electrons that are given off by the cathode are drawn to the anode and strike the tungsten target. The quantity of electrons given off depends on the temperature to which the filament is heated, and the speed at which the electrons travel across to the anode is determined, as we have already seen, by the amount of voltage impressed. The electron speed increases or decreases with the amount of voltage, which may be varied over a wide range.



A long step ahead—high-vacuum tube with tungsten target

Dr. Coolidge, fascinated by x-rays and their behavior, wanted to produce them at voltages higher than previously available. To do this, he found that he had to devise still another type of tube—a sectional x-ray tube. He developed what is known as the *cascade* principle to apply a part of the total voltage to each of a series of sections comprising the tube. The principle is applied today in the building of tubes for operation at a million or more volts. In the sectional tube, the electrons are accelerated by the voltage applied to each section as they pass through, and the resultant energy at the end section is the sum total of the individual boosts. For example, if a tube has five sections with a voltage of 100,000 applied to each one, the electrons will have as much energy as though 500,000 volts had been applied in one step.

Using this principle in the early stages, Dr. Coolidge and Dr. Ernest E. Charlton first developed equipment to operate at 800,000 volts. A unit was built for each of two hospitals to give high-voltage x-rays for cancer treatment. The tube was 14 feet long and a foot in diameter, and was energized by a bulky high-voltage generator which required a building 60x30x20 feet to house it. Still bigger is a 1,400,000-volt x-ray outfit built by General Electric for the National Bureau of Standards.

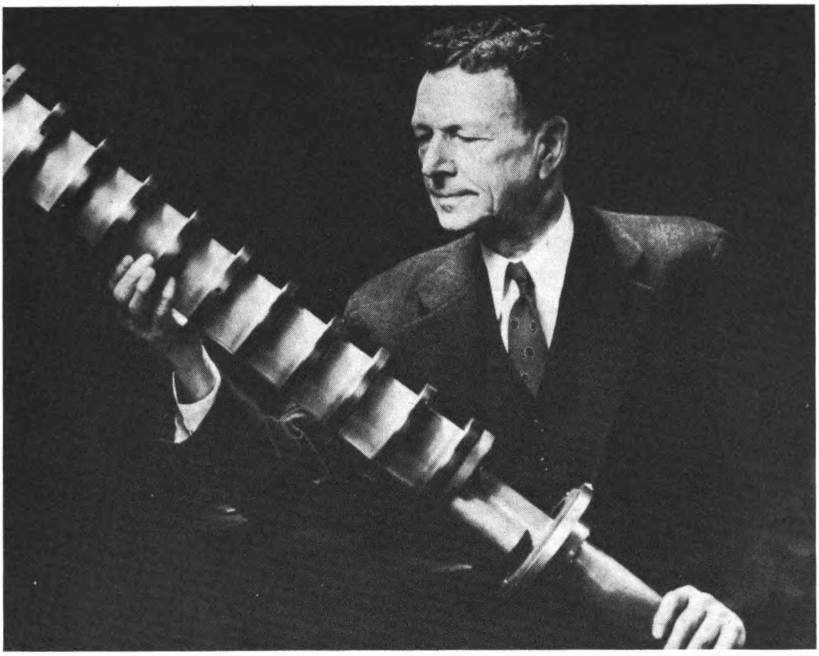
Eventually, through continued research under the direction of Dr. Charlton, tubes and transformers for operation at these exceedingly high voltages were made much more compact—reduced from an electrical giant requiring a special building to a unit hardly larger than a good sized barrel. General Electric had solved the problem of making million-volt units movable and adjustable. Paying tribute to Dr. Charlton and his associates for this achievement, Dr. Coolidge said, "The research work involved occupied the full time of an average of six men for a period of four years, and this, starting of course not from scratch, but with full knowledge of the x-ray equipment of the prior art."

The developments were mainly responsible for the newer million-volt units. Shock-proof x-ray equipment had previously used oil in the casing as an insulator. Now it was found that Freon gas, ordinarily used in electric refrigerators, could be pumped into the housing under pressure to serve as an effective insulator. This same gas is used in the million-volt and two-million-volt units today. Also, W. F. Westendorp developed a new type of transformer in which the iron core that ordinarily occupies the center of the coils of wire is eliminated. The multi-section x-ray tube, 30 inches long and 3½ inches in diameter, is placed in this central position, making for compactness and shorter electrical connections.

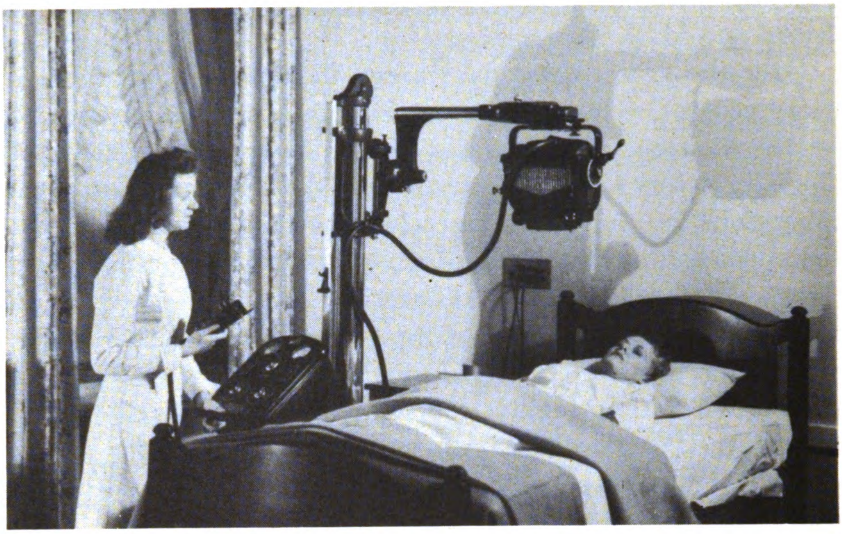
That Dr. Coolidge's discoveries and guidance in various research projects have wrought a profound change in our way of life is inescapable. He has obtained 83 patents himself. Equally important, he has helped and encouraged many who have become prominent in their own right in various fields of x-ray work—men like Charlton, W. F. Westendorp, Z. J. Atlee, and M. J. Gross.

Over the years, there were many men who contributed to x-ray science—Thomas Edison, for example, who discovered better fluoroscopic chemicals; J. B. Wantz, co-founder of the G-E X-Ray Corporation, who holds more than 50 patented inventions in the x-ray and electromedical field, and who has spent half a century building x-ray equipment; Sir William Bragg, "father" of x-ray diffraction; Debye, Scherrer, and Dr. A. W. Hull (the latter of the G-E Research Laboratory), who pioneered in the use of crystalline powder instead of a crystal in diffraction analysis; William Kearsley, Dr. Coolidge's assistant, who developed timers and stabilizers for better control of x-ray exposures; and Clyde Snook, whose mechanical rectifier produced better x-ray tube operation.

Dr. W. D. Coolidge with million-volt x-ray tube



X-RAYS IN MEDICINE



Mobile x-ray unit provides bedside service for hospital patients

NO MODERN hospital today is without its x-ray department, and every physician, surgeon, and dentist depends on the x-ray for diagnosis and prognosis in a large portion of cases. There is practically no region of the body that is not subject to its searching eye.

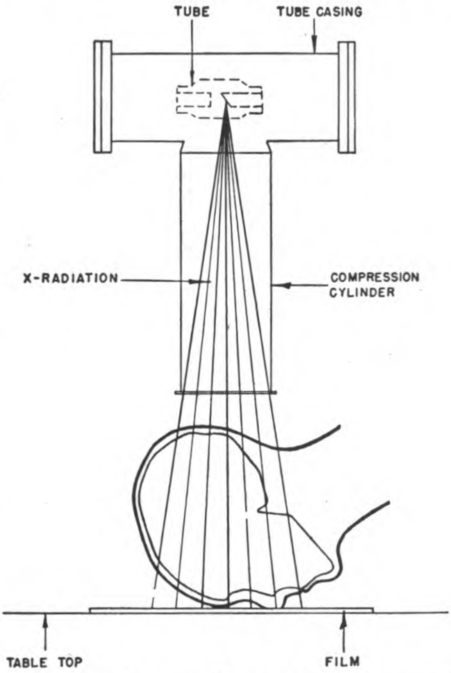
Medical radiology consists in the application of the x-rays and the radioactive substances, such as radium, to diagnosis and therapeutics.

In x-ray diagnosis, physicians and surgeons today can examine the skull, the spine, and other bones of the body; they can see that a broken bone is set properly, and how it is knitting; they can find gallstones, kidney stones, and bladder stones. Because tuberculosis of the lungs shows characteristic markings on the x-ray film, the presence of this disease can be accurately detected. X-raying is the one satisfactory method for discovering ulcers and tumors that might not be otherwise discovered until too late for treatment.

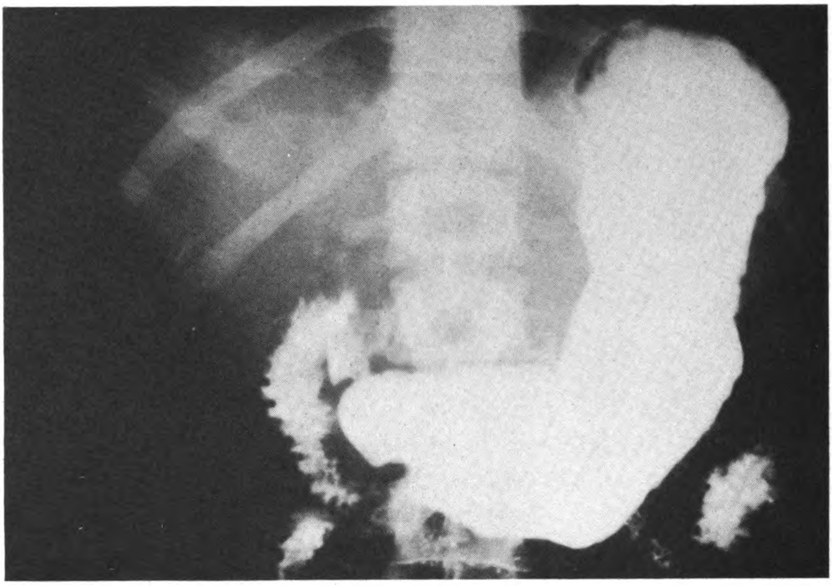
As an aid in diagnosis, x-rays provide two different methods of examination. One is known as radiography, whereby a permanent record of the x-ray image of various parts of the body is made on film. The other method is known as fluoroscopy, which affords a means of visual study of the x-ray shadow on a fluorescent screen.

An x-ray film, or radiograph, of any part of the body is similar to a photograph except that it is fundamentally a shadowgraph rather than a picture produced by reflected light. The source of "light" is an x-ray tube instead of ordinary lighting apparatus, and the "lights and darks" of the film depend upon the differences in density of the tissues situated in the path of the rays. The denser or the thicker the object, the more x-radiation will be absorbed by it, and less will reach the film. The amount of x-radiation which reaches the film—in a light-tight holder, under the patient's body—determines the amount of exposure which is expressed in terms of "black and white." So the greater the density or thickness of the object radiographed, the whiter will be that particular area in the film. The radiograph, therefore, is not simply a picture but a record of shadows of different parts, varying according to their respective densities or resistance to x-rays. It is from a highly skilled interpretation of the shadow images that the physician makes his diagnosis.

X-ray examination by fluoroscopy makes it possible to study internal organs in motion. The fluoroscopic viewing screen consists of a cardboard treated with chemicals which fluoresce—or give off visible light—when exposed to the action of the x-rays. When x-rays strike such a screen, either directly or after passing



"Lights and darks," on the film, depend upon density of object x-rayed



Radiograph showing opaque barium in a stomach

through some part of the body, an image in visible light is produced on the screen. The brilliance of the light and the details of the image depend upon the quantity and distribution of the rays striking the screen. The denser or thicker a given area of tissue, the more interference it will cause to the passage of rays, hence the darker the shadow upon the screen. Therefore, in fluoroscopy, the images of various organs are seen as dark shadows against an illuminated background.

Because of their lack of sufficient density, such internal organs as the stomach and intestines are not ordinarily clearly visible on the fluoroscopic screen or on the x-ray film. For this reason, the organs are filled with some substance comparatively opaque to x-rays to make it stand out clearly. A number of these radiopaque materials have been found that sometimes directly, sometimes indirectly, find their way into practically every organ of the body.

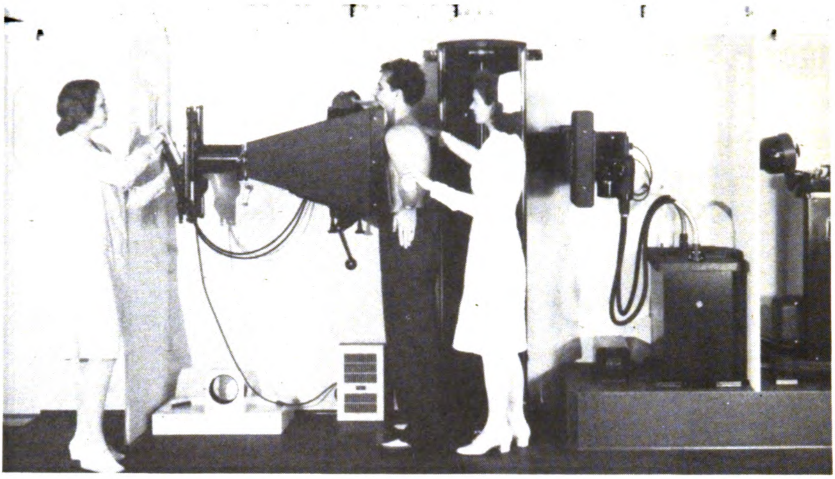
A person who has an x-ray examination made of his stomach, for example, will be given a milk-like substance to drink. Because the liquid contains barium sulphate, which is resistant to x-rays, the stomach and the intestines will then be outlined. In this way the radiologist can detect an ulcer, a cancerous growth, or other pathological trouble. Whether an examination is made radiographically or fluoroscopically, interpretation depends upon the physician's knowledge of normal and pathologic anatomy, physiology, and clinical medicine.

Another widely used—if highly specialized—method of x-ray diagnosis is known as photo-roentgenography, which is particularly well suited to mass x-ray chest surveys for the detection of tuberculosis. With conventional equipment, the x-rays pass through the patient's chest, throwing a full-size image directly upon a sensitized film. The film, usually 14 x 17 inches, must be the size of the chest because it is not possible to focus x-rays by means of lenses. The photo-roentgen equipment makes use of the customary type of x-ray apparatus to throw the image of the chest on a standard-size fluorescent screen. A small camera, equipped with a fast lens, is used to photograph the image upon a supersensitive film: 4- x 5-inch cut film or 70 mm roll films.

During the first World War, an x-ray chest examination was not a routine procedure for men inducted into the armed forces, with the result that the government later had to pay out more than a billion dollars in claims and hospitalization on tuberculosis cases which broke out while the men were in service.

When America entered World War II, photo-roentgen units were installed in induction stations throughout the country to examine the chests of all draftees to keep that tough, slender, wax-like little germ, the tubercle bacillus, from filtering into their ranks. Since these units produce an x-ray image of the chest on 4- x 5-inch film, instead of on the conventional 14- x 17-inch film, material costs were cut to about one tenth that of the older method.

During the first four years after Congress passed the Selective Service Act, about 12 million x-ray films were made at induction stations with photo-roentgen units, resulting in 120,000 deferments for chest conditions. In one instance, two

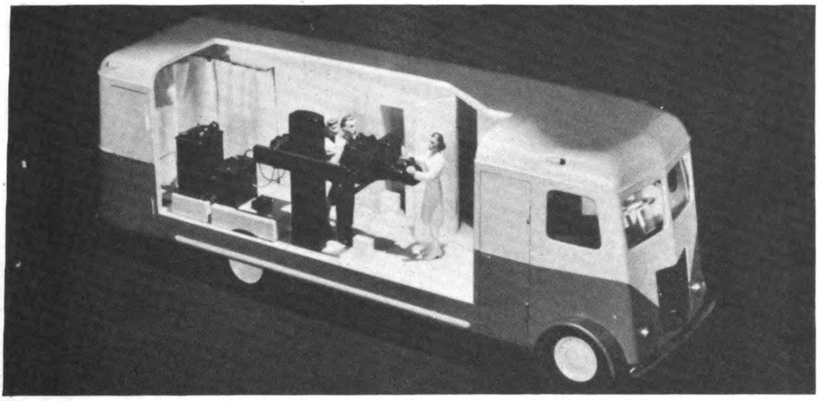


Interior of G-E photo-roentgen x-ray bus

thirds of a group, rejected because of a tuberculous condition, were not aware that they had the disease.

In an x-ray survey of 700,000 war workers and government employees, the U. S. Public Health Service found that 13 in every 1000 persons examined showed evidence of reinfection tuberculosis, and nearly two thirds of the newly-discovered cases were in the minimal stage. Health authorities, pointing to the importance of finding tuberculosis in its early stages, contrast this result with an estimate that from 60 to 90 per cent of the 90,000 patients now in sanitoriums were not recognized as having the disease until it was far advanced. Installed in mobile laboratories, G-E photo-roentgen units make it possible for public health and welfare organizations to reach and examine thousands of persons not only in large cities, but in rural areas and in thinly populated sections too. The National Tuberculosis Association estimates that each year there are at least 200,000 unsuspected cases of the disease, and that x-ray machines, capable of producing two complete chest films a minute, provide a potent weapon in the nation-wide fight to eliminate the disease.

X-rays play an important diagnostic role in dentistry, too. The usual clinical examination is inadequate because it is



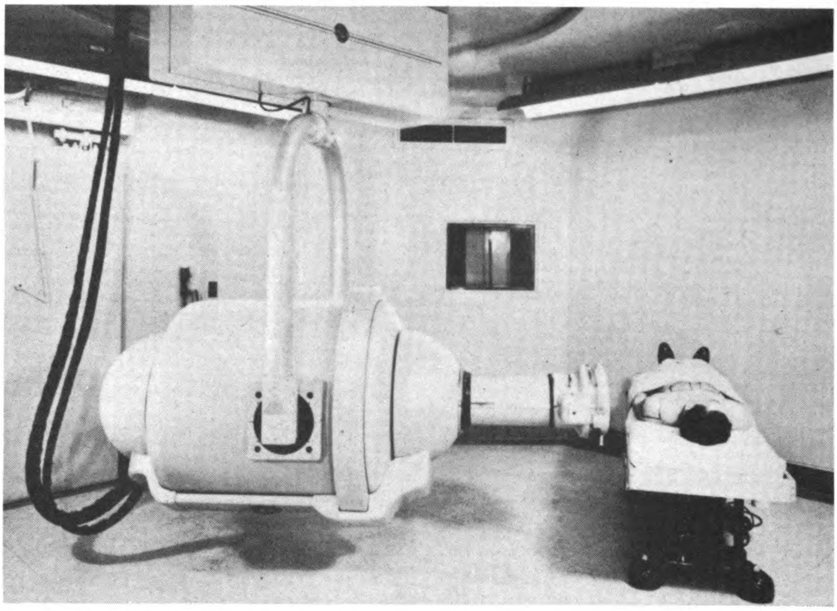
Scale model of mobile x-ray unit for mass chest x-ray examinations

limited to the visible surfaces of the teeth and the superficial tissues of the mouth. Certain areas of the teeth cannot be examined except by x-rays. The chronic infections at the end of tooth roots which contribute to grave systemic disease rarely give warning by local symptoms or visible changes. Decay in the contact surfaces of teeth and underneath repairs may invade the tooth pulp before being discovered by instrumental examination.

When you have your teeth x-rayed, the radiographs show the state of health of each tooth, down to the bony socket where the root of the tooth is imbedded. They show a cavity which is hidden by another tooth. Or they may show an abscess way down at the tip of a tooth that looks healthy.

Therapeutically, x-rays have been found useful in treating approximately 80 skin disorders, as well as acute infections, inflammations, gas gangrene, and malignant diseases. Living tissues undergo certain changes when exposed to x-rays or radium. X-rays passing through the tissues of the body are partly absorbed, producing changes in the physiologic and biologic sections of the tissues. Tissue changes vary according to various factors, chief of which are the quality and quantity of the rays, rate of administration, intervals between treatments, size of exposed field, and possible previous exposures to x-rays.

A most effective weapon in the fight against deep-seated



Million-volt x-ray therapy unit at an Army hospital

malignancies, like cancer, is General Electric's million-volt x-ray unit. Such equipment has been installed in St. John's Hospital, Cleveland; Memorial Hospital, New York City; the State Institution for the Study of Malignant Diseases, Buffalo, N. Y.; and the Army Medical Center, Walter Reed General Hospital, Washington, D. C. X-radiation equivalent to that of about 8½ pounds of radium is produced by these powerful units.

While the million-volt unit might be considered the husky glamor boy in the radiation therapy field, it is by no means the only equipment used for this type of work. X-ray units, especially designed for therapeutic applications operate at 800,000, 400,000, 250,000, 200,000, and 140,000 volts.

The physics of radiation therapy is closely associated with three factors: the *intensity* and *quality* of the radiation, and the *distribution of energy* within the tissues.

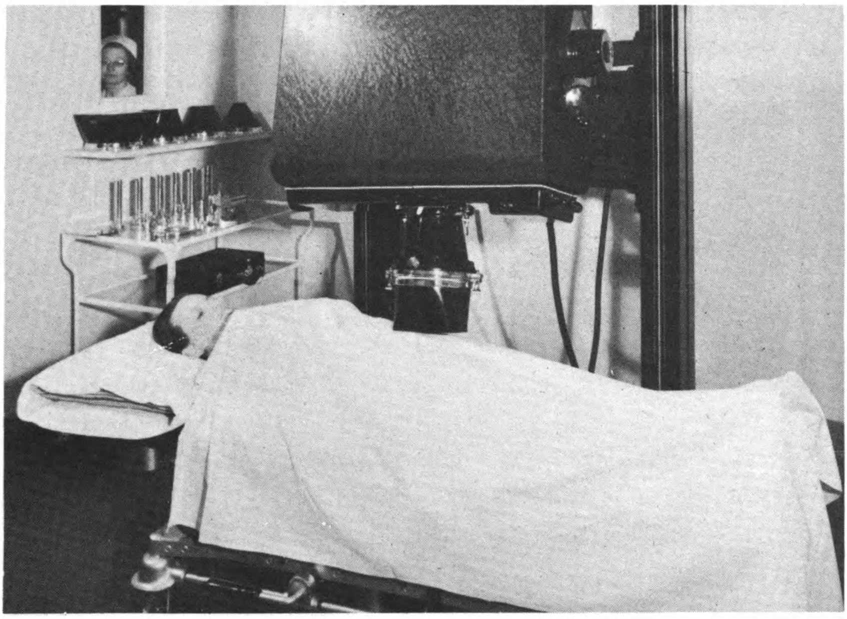
The first factor, intensity, has to do with the quantity of radiation reaching the patient's body.

The second factor, the quality of the radiation, involves the wavelength of the rays reaching the patient's body. One of the problems of radiation therapy is that of getting sufficient radiation to a tumor within the patient's body without destroying the intervening tissues through which it must pass. The better the quality of radiation—in other words, the shorter the effective wave length—the greater the quantity of radiation that can be delivered to the tumor without irreparable damage to the intervening normal tissue. Correlating intensity and quality, the shorter the effective wave length, the greater the dose of x-rays may be.

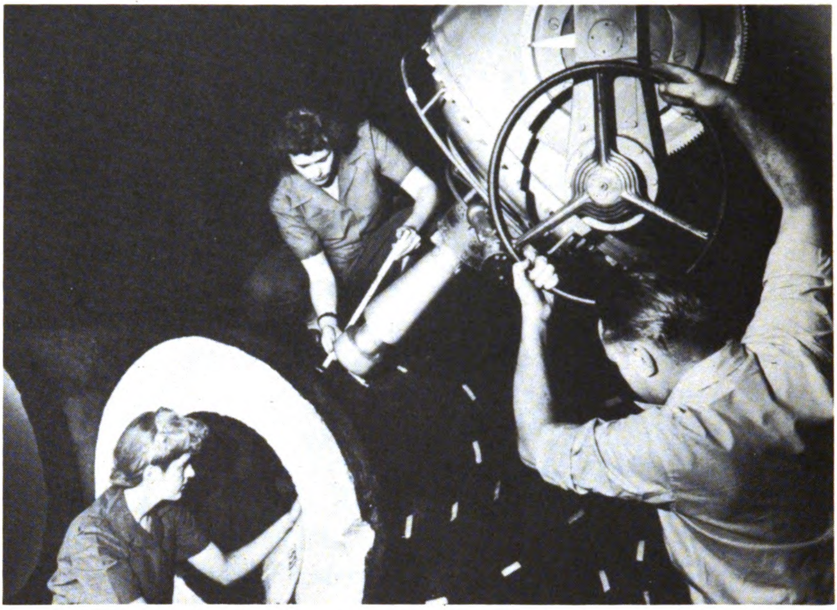
As for the third factor, the distribution of energy within the tissues, the effectiveness of any beam of irradiation depends upon the portion of its energy that can be delivered into and absorbed within the depths of the lesion.

It is estimated that about 300,000 people in the United States have some form of cancer, and, since the cancer disease lasts on an average of two years, 150,000 patients are seen by the medical profession each year. Thousands of cases, especially those involving small lesions, respond effectively to x-ray treatment.

A patient under a 250,000-volt x-ray therapy unit



X-RAYS IN INDUSTRY



Million-volt unit positioned for x-raying big casting

THE use of high-voltage x-rays in industry is not new. Rather, the story is one of early recognition and then a long period of development, leading to efficient, shockproof, high-power apparatus that is in use in our industrial plants from coast to coast.

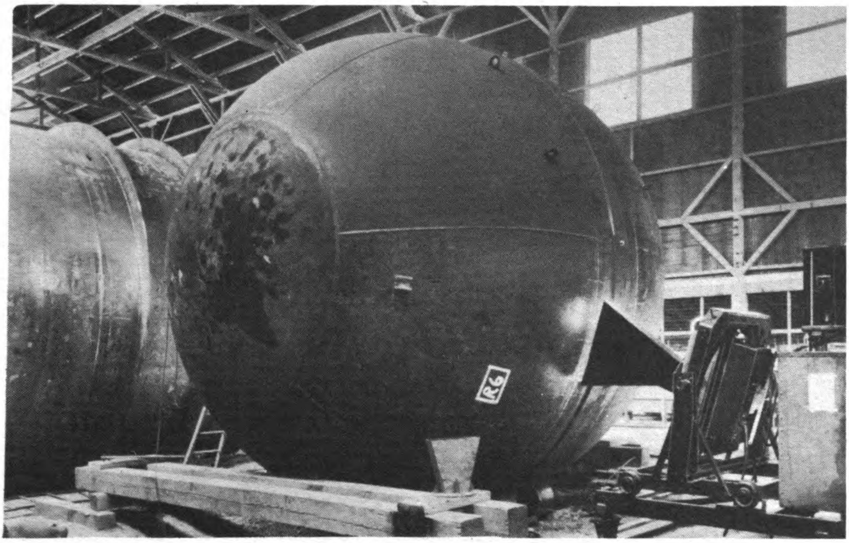
The first commercial use of x-rays in the United States began in 1922 when, after a long period of development and research, x-ray transformers, controls, and tubes reached a degree of perfection that made possible the use of relatively high voltages. Continued development has resulted in the use of gradually increasing voltages until now x-ray equipment operates safely and economically at one and two million volts.

Much of the pioneering work in the development of x-rays for non-medical purposes was done at the Watertown Arsenal where the War Department, in 1922, authorized installation of a 200,000-volt mechanically rectified G-E x-ray transformer. It was used to further the development of better foundry techniques and, thereby, to insure sound castings. Colonel Dickson, then commanding officer, and Dr. H. H. Lester, chief physicist, were the men who pioneered in industrial radiography at the arsenal. From their work, and from the experiments carried on in General Electric's Research Laboratory, much was accomplished in developing practical applications of x-radiation.

With distressing frequency castings turn up containing cracks and blowholes. Sometimes there is marked evidence of these defects on the surface, sometimes none at all. More frequently a casting will show slight signs of possible faults on the surface, but the engineer is left in doubt as to whether he is confronted with superficial markings or apparently trifling defects that will widen out into large fissures or cavities. Many important and expensive castings have been scrapped because the engineer dared not risk using them.

Unless x-rays are employed, metal castings of many kinds can only be inspected for hidden defects by destructive methods. The same holds true in inspecting metal welds. A War Department factory director once remarked that destructive methods of inspection are "like striking a match merely to see if it is a good one." X-rays provide industry

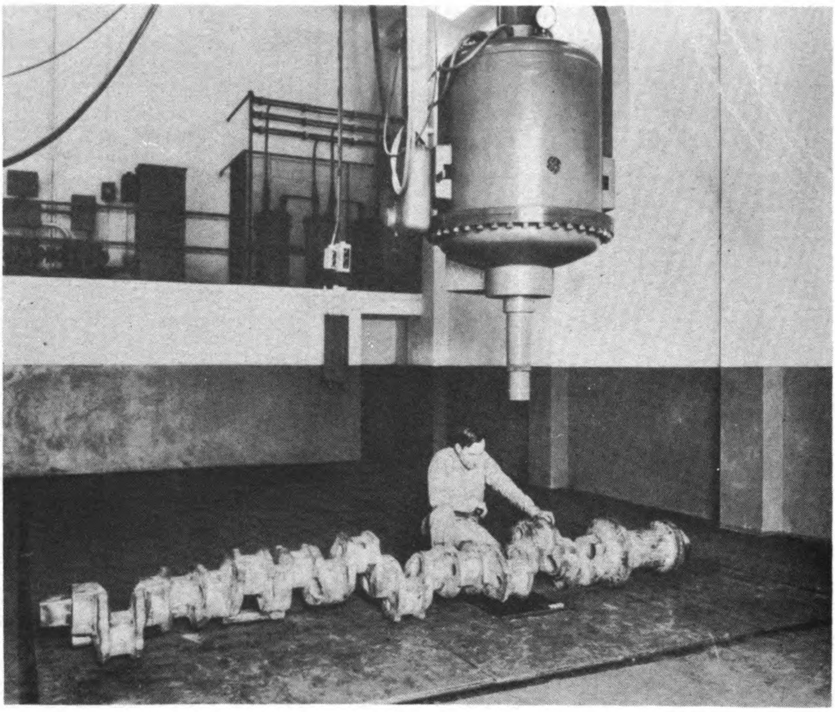
Radiographing welds in steel plug at Grand Coulee Dam

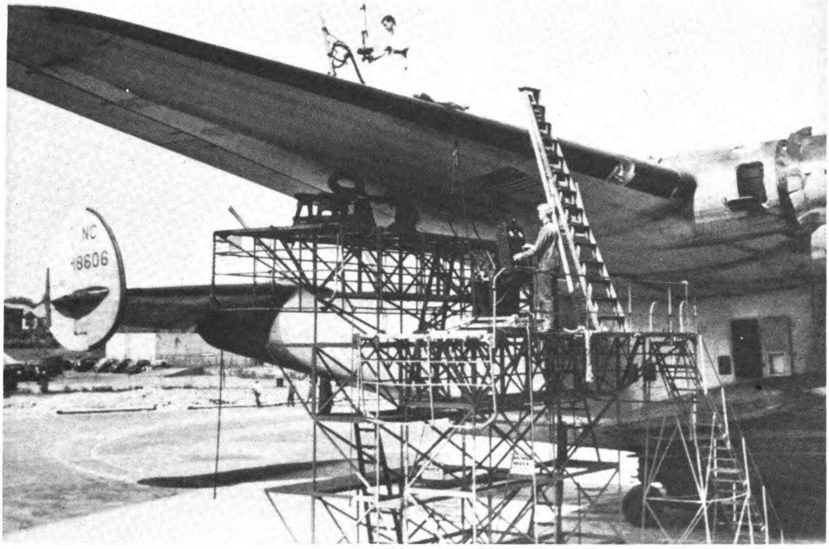


with a means of seeing into and learning a great deal about the interior of many articles without destroying or in any way harming them.

Frequently, the first batch of castings from a new design is radiographed. If any faults are found, modifications are made in the design or the method of casting until radiography shows that the defects have been eliminated. The strength of a weld, too, depends greatly on the skill and the care taken by a workman in making it. X-rays went to work in the field of welding several years ago when leading manufacturers of high-pressure boilers wanted to change from riveting to welding as a standard construction method. Manufacturers then adopted the x-ray to examine completed welds, learned to diagnose defects and their causes, and used radiographs to show welding operators these defects—and the mistakes that caused them.

G-E million-volt x-ray unit speeds inspection of huge marine diesel engine crankshaft



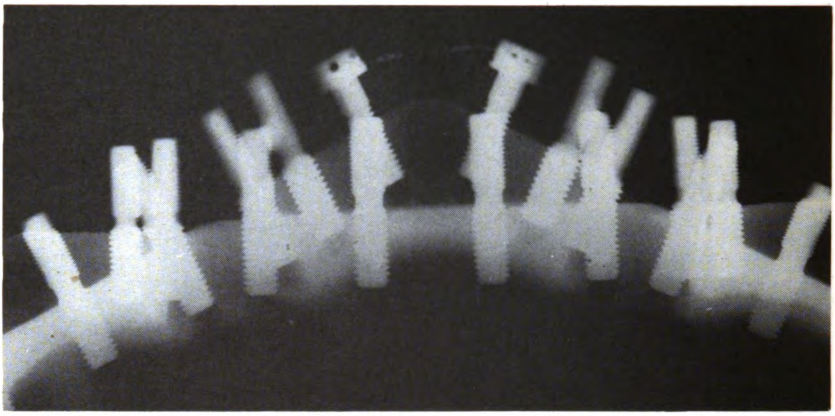


For safe air travel, Pan American World Airways uses a G-E portable x-ray to find flaws in steel

While the x-ray makes for accuracy in metallurgical inspection work, another practical advantage, from an industrial standpoint, is speed provided through the constant development of new super-voltage equipment and improved technique. Both were combined to their fullest extent for maximum production during the war emergency.

An important and spectacular industrial tool—especially in wartime—is General Electric's million-volt shockproof x-ray unit. This unit can penetrate heavy plates of steel in a few minutes. It is less than five feet high and three feet in diameter and weighs about 1500 pounds. A few years ago radium, at $135,000 a gram, was the only source of the same kind of short-wave-length radiation. Now radiation from this powerful x-ray unit is equivalent to that produced by 8½ pounds of radium with the machine itself costing only a small fraction of what radium would cost even at the recent valuation of $30,000 a gram; and the result is a sharper radiograph.

A Detroit manufacturer used 16 different types of x-ray units to speed up production of war materials—parts for tanks, bombers, gun mounts, armor plate, aircraft engines, turbosuperchargers, truck and jeep engines, and gun directors.



Radiograph of an airplane motor's crankcase showing exact position and depth of studs

At one time during the war period, x-ray departments in that plant employed 125 people, and the company maintained an apprentice training school to teach civilians how to operate the equipment and to process films.

This company used a million-volt x-ray unit to inspect crankshafts for a 500-horsepower tank engine, and also heavy castings for a light armored car. Every 250-pound crankshaft built into a tank engine underwent radiographic inspection with the million-volt unit. It took only 17 minutes to radiograph 12 crankshafts.

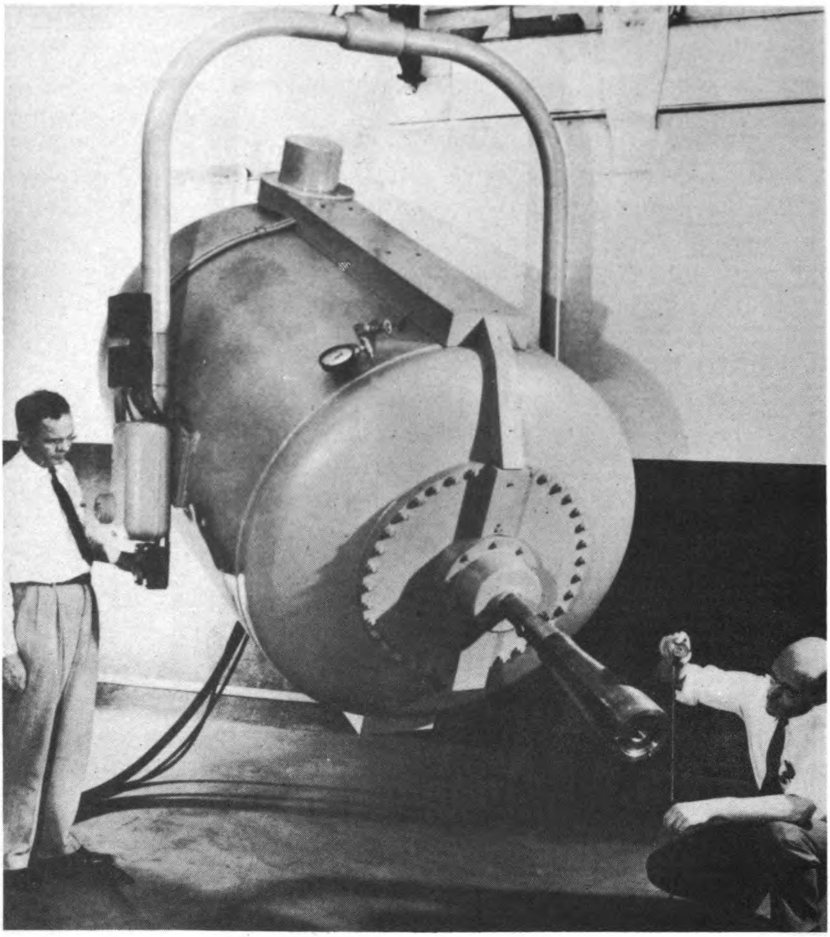
Navy yards found x-ray units almost indispensable in building battleships better and faster than those of enemy powers. Million-volt machines have operated day and night during war days in many of the 23 privately-owned ship yards, as well as in government-owned yards at Norfolk, Philadelphia, Pearl Harbor, and Boston.

At the Philadelphia Navy Yard, where battleships like the USS *New Jersey* and the USS *Wisconsin* were built in record time, the million-volt unit inspected steam-pressure castings weighing from 200 to 1500 pounds. It found the defects and showed them on the developed film.

Engineers at the Philadelphia Yard placed 20 castings in a circle around the target of a million-volt unit, and all were radiographed simultaneously with a single two-minute exposure. Doing the same job with gamma rays, produced from a practicable amount of radium, would have taken four hours. Also, portable x-ray units inspected welds in high-pressure pipes that carry steam from one end of the ship to the other. There are 1800 vital high-pressure welds on a battleship, and all of them were inspected by the x-ray.

Another development—resulting from long research—is a two-million-volt x-ray unit. This unit, consisting of a low-frequency resonance transformer and a sealed-off multi-section x-ray tube, weighs only 5000 pounds and is mounted on a crane, making it possible to move the unit into all positions for various radiographic techniques, utilizing both the reflected and the transmitted x-ray beam. In the million-volt unit the electrons, on their way to the target, were speeded in 12 steps, but the newest two-million-volt tube has 24, averaging 83,500 volts at each stage. Construction of the tube was made possible by the use of rings of fernico between the sections of glass. Fernico is an alloy with the same heat expansion as glass, and so the metal and glass can be fused directly together. This more flexible tool, developed during the war period, can be used for the radiographic inspection of steel up to 12 inches of wall thickness.

In radiographing an eight-inch steel casting the 2-million-volt machine is 78 times as fast as the million-volt unit. Under one typical set of conditions, four and a half hours are required to make an exposure with one million volts. Two million volts does it in three and a half minutes. For still thicker sections the ratio is even greater. Two-million-volt x-rays make a satisfactory exposure through a foot of steel in about two hours when the Type A x-ray film is used, at a distance of three feet from the end of the tube.



General Electric's new 2-million-volt x-ray unit

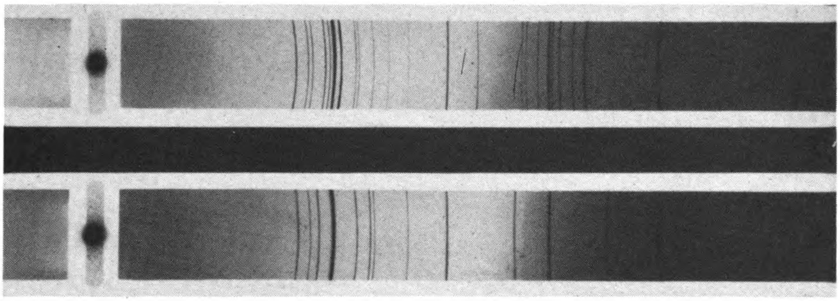
Industrial x-ray units, operating at less than 50,000 volts, are used largely for diffraction studies of the atomic structure of matter. This may be one of the fields in which x-rays have their potentially widest use, since crystal analysis by x-ray diffraction may be made with almost any conceivable material. It has applications in metallurgy, physiology, pathology, biology, and the process industries.

In fact, x-ray diffraction is one of the most fascinating applications of electronics. When a specimen of any material is placed in a beam of x-rays, each atom in the specimen scatters the rays in all directions, just as ripples are scattered on the surface of water by a falling pebble. If the specimen is crystalline, the atoms are stacked up within it in an orderly manner, and the x-rays they scatter cancel each other except in a number of particular directions. These *diffracted* x-rays can be recorded on a sensitized film as a diffraction pattern.

Each regular arrangement of atoms—that is to say, each kind of crystal—produces its own characteristic x-ray diffraction pattern, according to the way its atoms are piled together. For instance, all of the oxides of iron have different regular arrangements of atoms, so that they can be identified readily by means of their diffraction pattern—even in mixtures—although they cannot be distinguished accurately by any other method.

It is also possible by means of x-ray diffraction to follow the structural changes in metals while they are being worked or heat-treated; to classify even such slightly crystalline materials as cotton, wool, silk, and other natural and synthetic fibers; to analyze mixtures of crystalline substances; and to discover the atomic arrangements in solids.

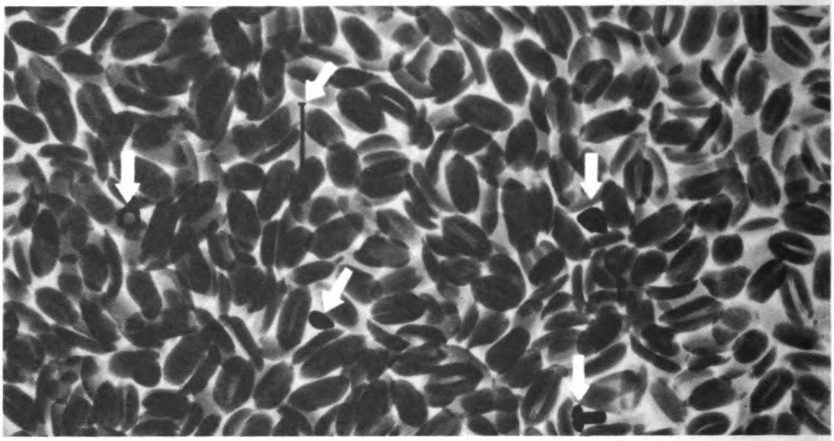
Diffraction patterns—showing carbides in molybdenum steel



A quite different type of industrial x-ray application—that of fluoroscopy—permits production-line inspection of small aluminum and magnesium castings.

The fluoroscopic or visual x-ray inspection method has found its widest industrial use, however, in the food industries. Here it is of tremendous importance that every particle of foreign material which may have found its way into the product before or during the manufacturing process be detected and removed. The x-ray provides an inspection method which may be applied at practically any stage of manufacture.

Usually, the products to be inspected are carried on a conveyor belt over the source of x-radiation—the x-ray tube—and under the fluoroscopic viewing screen. Stationed in a darkened booth, or looking through a darkened hood, the operator sees on the screen a brilliant image of the material being carried on the conveyor belt. Since the images of foreign materials will have the same relative positions on the screen as the materials themselves have in the product under inspection, it is a simple matter to determine their locations and remove them without disturbing unaffected parts. With many packaged products there is sufficient definition to allow the inspector to detect a shortage in the fill of the container, in addition to discarding foreign bodies which may be present.

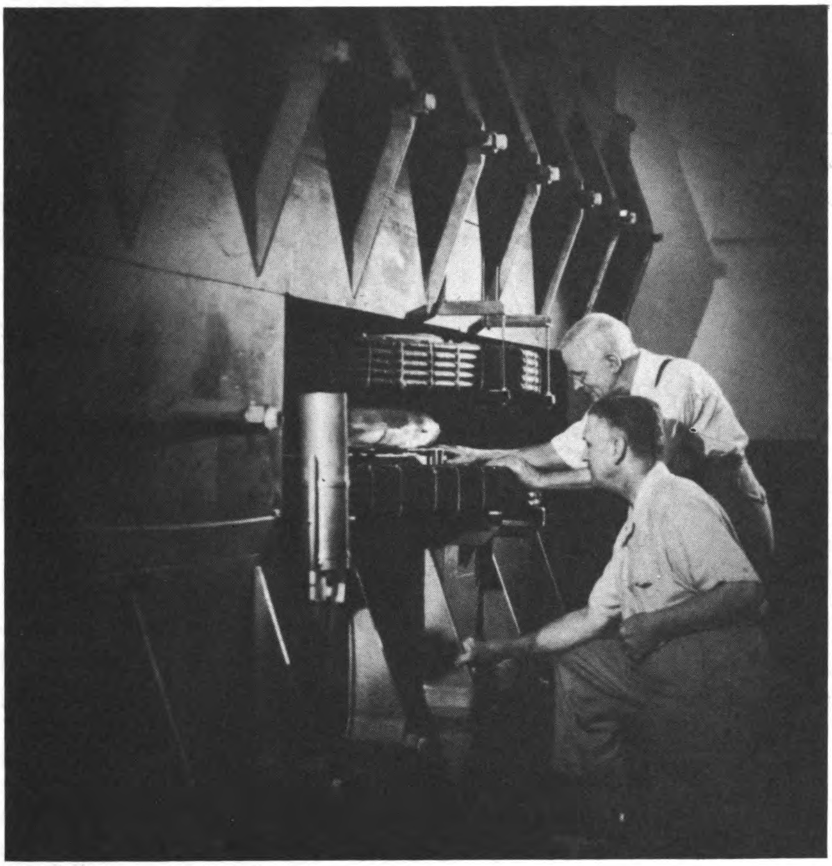


Radiograph—foreign objects show in trayful of peanuts

Fluoroscopic x-ray units, utilizing the conveyor system, have been designed and built for the inspection of bulk products, such as citrus fruits, diced vegetables, peas, corn, barley, rice, coffee, beans, peanuts, and a wide variety of other materials. These units can also inspect products packed in cardboard, cellophane, or thin wooden containers. In effect, visual x-ray examination gives the food inspector an opportunity to look *through* instead of *at* a material.

NEW VISTAS IN X-RAY

TODAY one of the most fabulous chapters in the story of x-ray development is becoming more and more widely known. With the help of several powerful new machines, popularly known as "atom smashers," x-ray scientists have opened up wide vistas in the production and uses of x-rays.



Operating at maximum power, the betatron produces x-rays of 100,000,000 electron volts

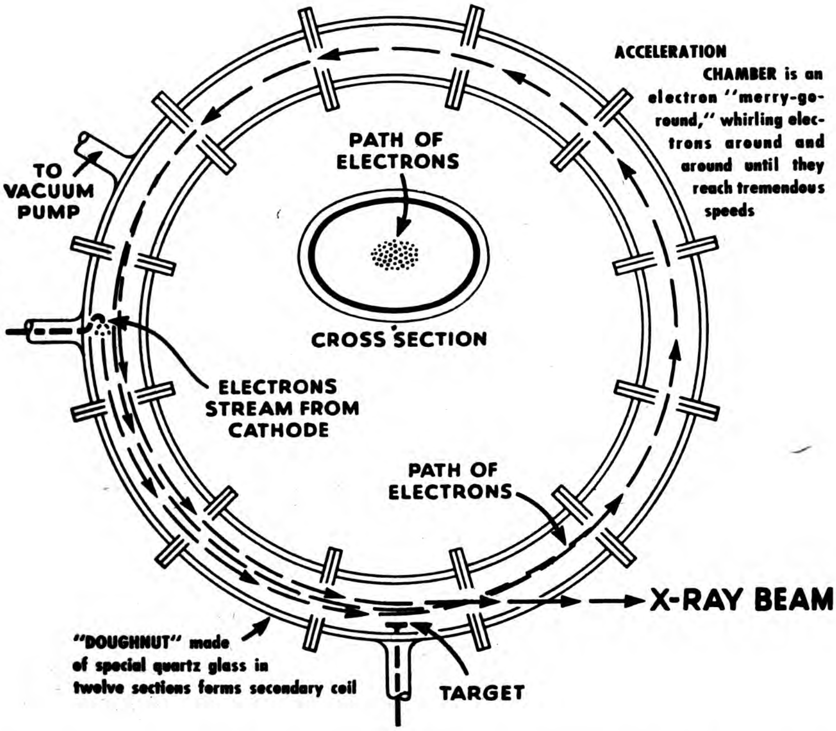
This new chapter had its beginning some time before World War II when fundamental studies of atomic and sub-atomic structure were undertaken. The ultimate goal of these studies was to unlock the secret storehouse of atomic energy which resides in the nucleus, that complex and little understood kernel within the atom. But the war interrupted these studies. During the war years, all efforts at the conquest of atomic energy were concentrated upon its application to military weapons. The climax of these efforts came with the development of the atomic bomb. With the return of peace, the aim of nuclear research is once again a fuller understanding of the truths of nature and the control of atomic energy to the eventual benefit of all.

The attack on the atomic nucleus demanded a battery of especially designed "heavy artillery." For, in exploring the nucleus, giant machines must fire atomic particles, such as electrons or ions, at tremendous speeds into the hearts of atoms. In some cases, these sub-atomic bullets, instead of reacting directly with the target material, excite high energy x-rays which, in turn, produce the nuclear reactions. Thus, nuclear research gave birth to a new and powerful family of x-ray generators.

Such powerful devices for producing high-speed projectiles are broadly known as "particle accelerators." And one of the earliest weapons in this battery of heavy artillery was the cyclotron. A massive electromagnetic device, the cyclotron spins positively charged pieces of atoms, called ions, between the poles of a powerful electromagnet until they have reached very high velocities and pour forth in a stream of high-speed projectiles to bombard a target. The cyclotron is a very useful tool in nuclear research, but it is not suited to the production of x-rays because its projectiles are ions rather than electrons.

A more recent accelerator designed especially for electrons is the betatron. In this instrument, electrons are ejected from a hot filament or "electron gun" which projects into a doughnut-shaped vacuum tube. They travel in circular paths inside the "doughnut" under the influence of an intense magnetic field. Whirling around in the vacuum chamber, the electrons are accelerated more and more with each trip until their speed closely approaches that of light. When periodically a pulse of electricity is applied to alter the magnetic condition, the path of the electrons is shifted. X-rays are produced when these speeding electrons crash into a tungsten target that stands in their way—x-rays corresponding to voltage up to 100,000,000 volts.

The forces which operate in the betatron are exactly the same as those of a transformer. In the transformer, the incoming current flows through a coil of wire, known as the primary, and by induction a current is caused to flow through another coil, the secondary. This current consists of a flow of electrons from one copper atom to the next. In the betatron, the secondary is not a coil of wire, but the doughnut-shaped vacuum tube.



ACCELERATION CHAMBER is an electron "merry-go-round," whirling electrons around and around until they reach tremendous speeds

"DOUGHNUT" made of special quartz glass in twelve sections forms secondary coil

Several of these new machines in the 10-, 50-, and 100-million-volt range have been designed and built in the General

Electric Research Laboratory. The giant of this family is the 100-million-volt betatron shown in the illustration. Weighing 135 tons, this machine produces x-rays far more powerful than any previously attained and is capable of penetrating a thickness of metal considerably greater than will the 2-million-volt rays. Creation of matter from energy—reverse of the process in the atomic bomb—can also be accomplished with radiation from this giant atom smasher.

The newest unit of this atomic armor-piercing battery, the G-E 70-million-volt synchrotron, is a first cousin of the betatron, also using electrons as projectiles. In this device, the action of the magnetic field is supplemented by a high-frequency electric field, so timed as to give the electrons a "kick" every time they pass through an electrified tunnel in their course. Like the betatron, it is a powerful source of x-rays, but its total weight of only eight tons is of particular advantage. The synchrotron principle offers the possibility of reaching energies of the order of a billion volts. It will then be possible to perform controlled laboratory experiments with energy ranges heretofore available only in cosmic rays. The artificial production of mesons, a discovery of cosmic ray research, is another possibility with far-reaching implications.

The final fruits of these basic researches in the laboratory are to be found in their many applications to modern technology. In the field of industrial radiography, for instance, a new 10-million-volt betatron will supplement the present one- and 2-million-volt G-E x-ray equipment and will provide for easy inspection of increased thicknesses of steel and other metals. For use in medical research, a 50-million-volt betatron will facilitate experimental work in cancer therapy. In the vast, fundamental field of nuclear research, projected machines of tremendous voltage and power will enable us to extend our knowledge of the atomic nucleus, and it is entirely possible that other such practical consequences of pure science as atomic fission may be forthcoming.

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